



The Power Problem in Superbubbles

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Adiabatic shell evolution

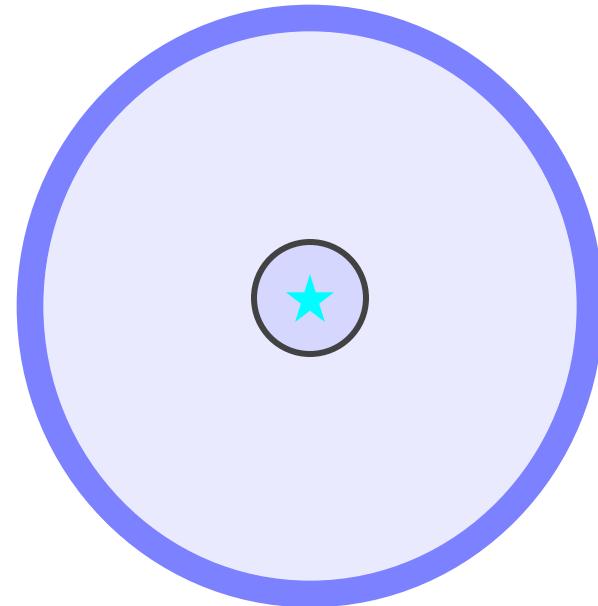
$$R \propto \left(\frac{L}{n} \right)^{1/5} t^{3/5}$$

$$v_{\text{exp}} = \frac{dR}{dt} \propto \left(\frac{L}{n} \right)^{1/5} t^{-2/5}$$

$$L = \frac{1}{2} \dot{M} v_{\infty}^2 \quad \text{stellar wind}$$

$$L = \frac{N_* E_{51}}{t_e} \quad \text{SNe}$$

Pikel'ner (1968); Castor et al. (1975);
Dyson (1977)



L = mech luminosity
n = ambient density
t = age

Simulations: Mac Low et al. (1989); Bisnovatyi-Kogan et al. (1989); Palous et al. (1990); Tenorio-Tagle et al. (1990); Tomisaka (1991); Silich et al. (1996); Gazol-Patino & Passot (1999); Strickland & Stevens (2000); others...



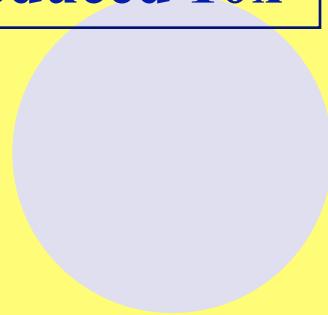
The Problem: Growth rate discrepancy

Comparing to standard
adiabatic model

observe:

R , v , stellar pop

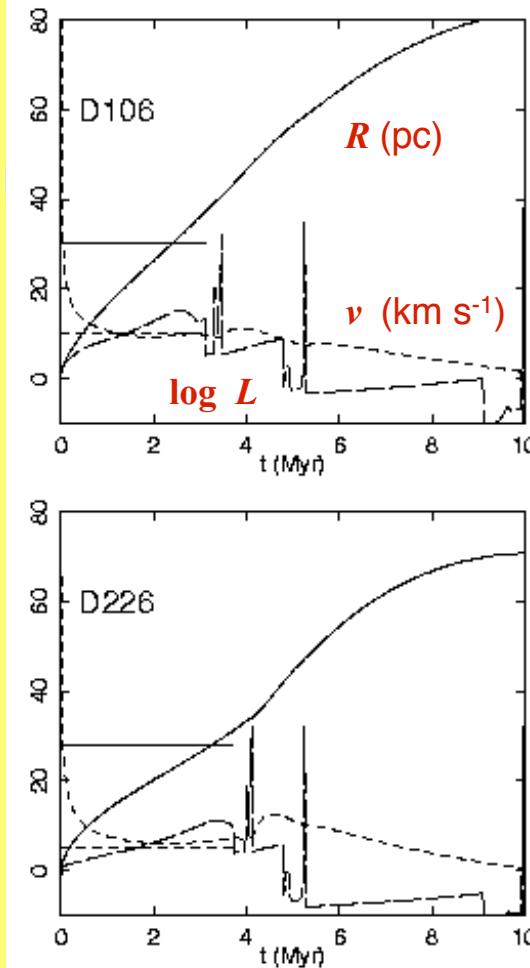
L/n reduced 10x



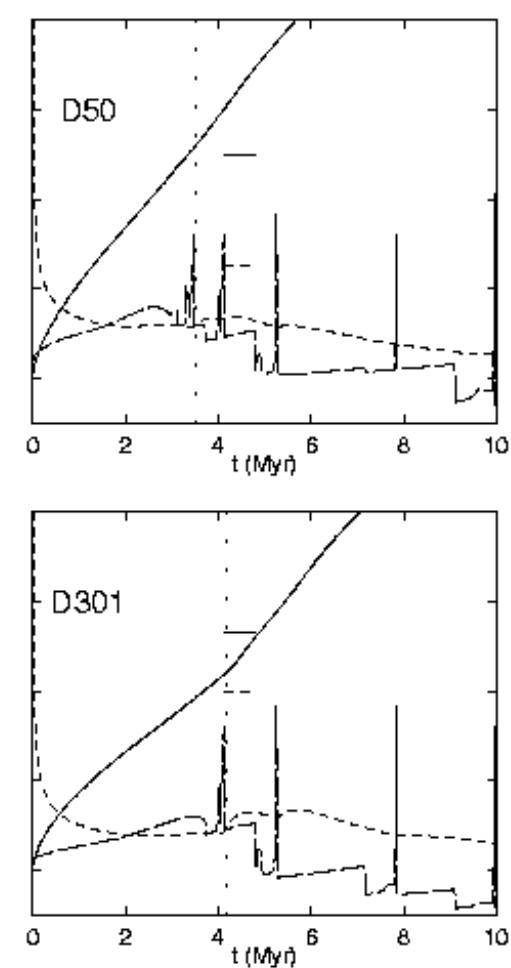
See also:

- Saken et al. (1992)
- Brown et al. (1995)
- Oey & Massey (1995)
- Oey & Smedley (1998)
- Cooper et al. (2004)

X-ray dim
Low [S II]/H α



X-ray bright
High [S II]/H α



LMC Superbubbles

Oey (1996)



Possible solutions

1. Input power, \dot{M} overestimated for winds

1. X-ray line profiles (*Cohen et al. 2006; Miller et al. 2002; Kramer et al. 2003*)
2. P V line profiles (*Fullerton et al. 2006*)
3. Clumping (e.g., *Crowther et al. 2002; Bouret et al. 2005; ...*)

up to factor of 100 ?!
winds only

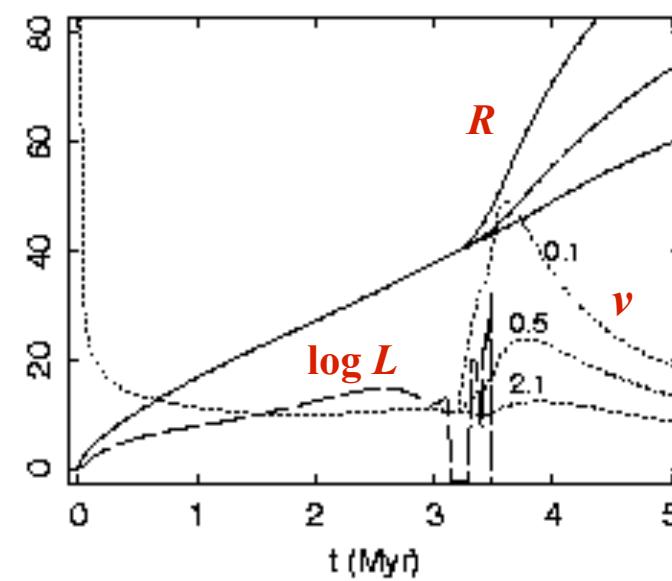


Possible solutions

2. Ambient density underestimated

Ambient density mini-blowouts

→ Gas distribution



Oey & Smedley (1998)

also Mac Low et al. (1998)





H I



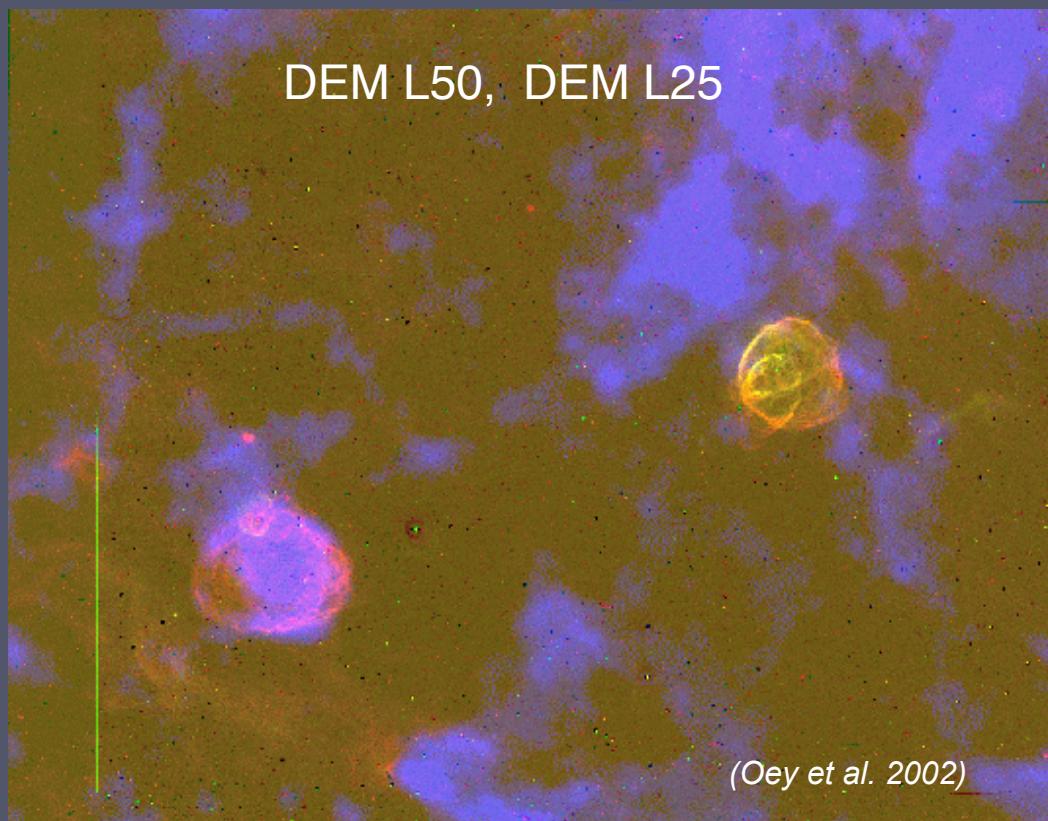
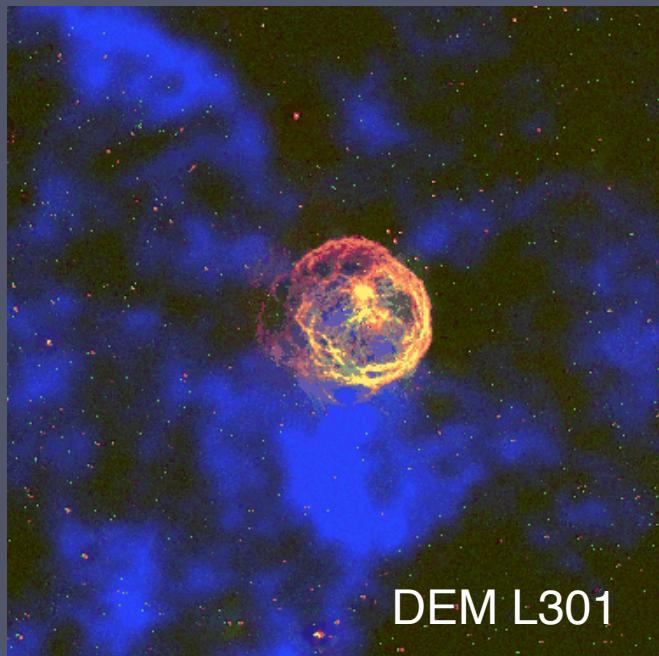
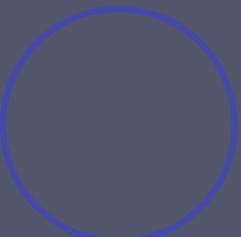
H_α



[O III]



Diverse environments!



Possible solutions

3. Ambient pressure underestimated

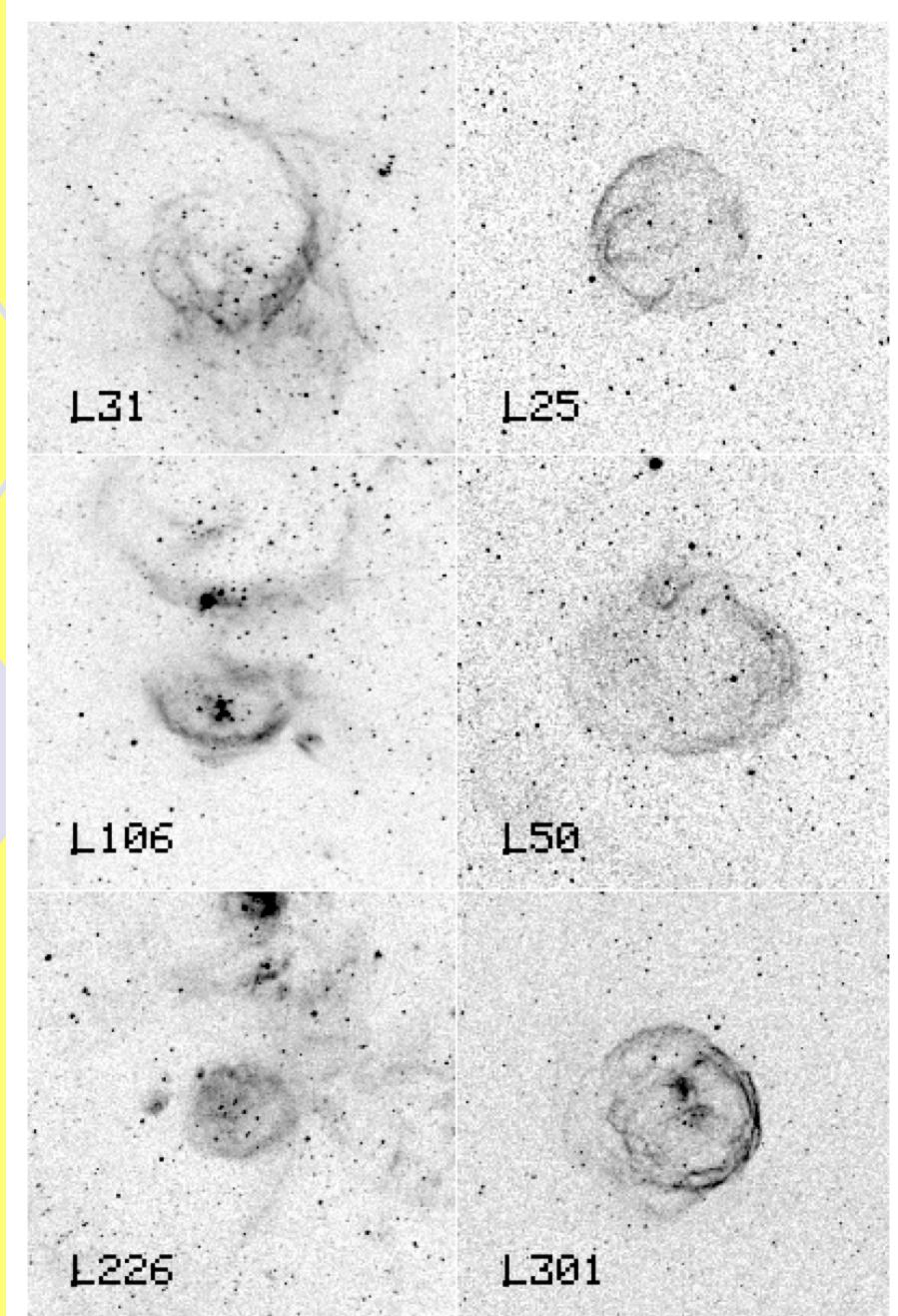
Oey & Garcia-Segura (2004)

1. Thermal
2. Magnetic
3. Turbulent
4. Cosmic ray

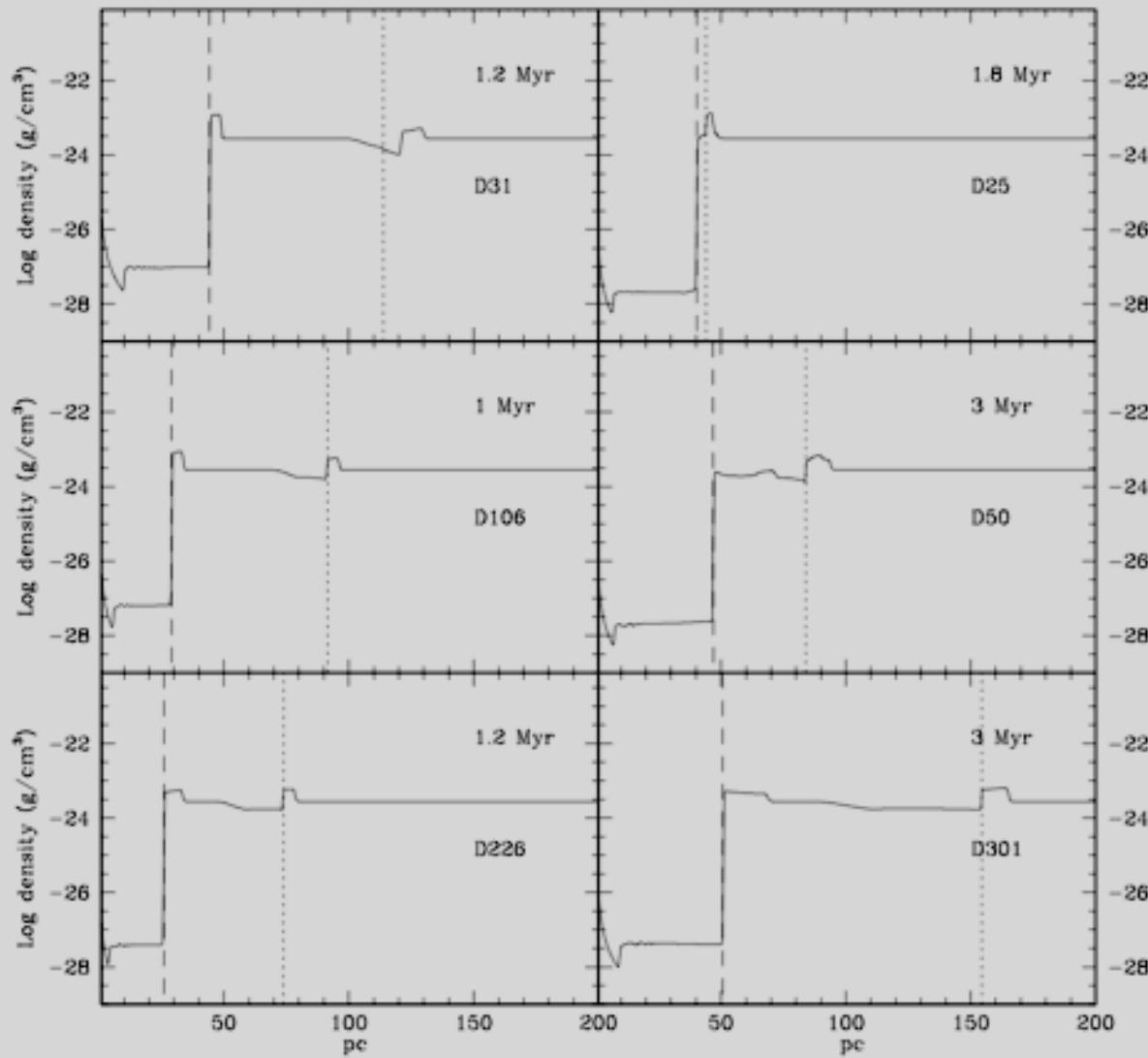
Correlate with SFR

factor of 10 ?

$H\alpha$



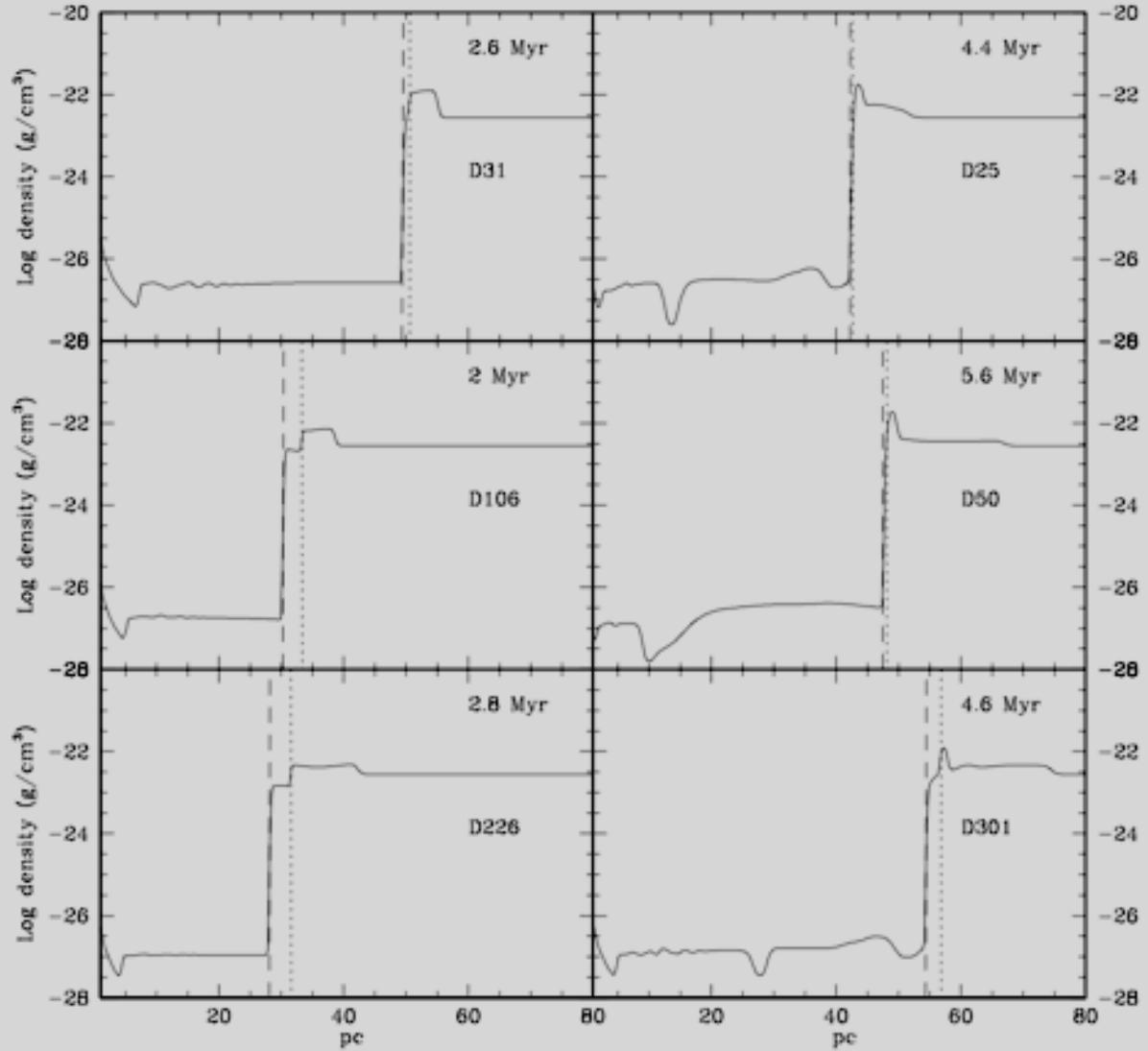
ioniz edge



$$P/k \sim 1 \times 10^4 \text{ cm}^{-3} \text{ K}$$

Oey & Garcia-Segura (2004)





$P/k \sim 1 \times 10^5$
 $\text{cm}^{-3} \text{ K}$

Oey & Garcia-Segura (2004)



Possible solutions

4. Cooling

e.g., mass-loading

Cowie *et al.* (1981)

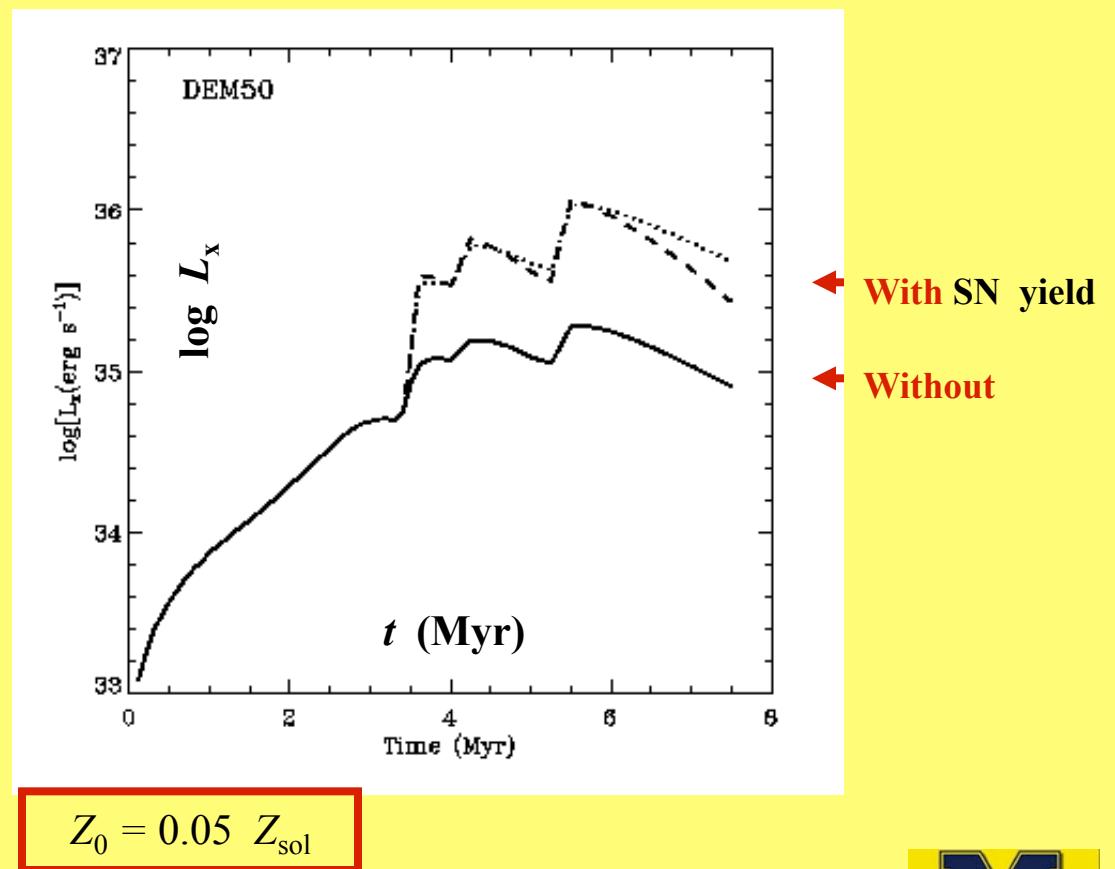
Hartquist *et al.* (1986)

metallicity

Silich *et al.* (2001)

factor of < 10

Silich & Oey (2002)



Possible solutions

5. CR acceleration

see *Parizot et al. (2005); Bykov (2001)*

Higher CR acceleration efficiency within superbubbles:

- SNRs expand into pre-heated medium (e.g., *Parizot et al. 2005*)
- Stronger MHD turbulence & magnetic fields
(e.g., *Bykov 2001; Bykov & Toptygin 1987*)
- Promote multiple accelerations
(*Parizot et al. 2005, Klepach et al. 2000*)

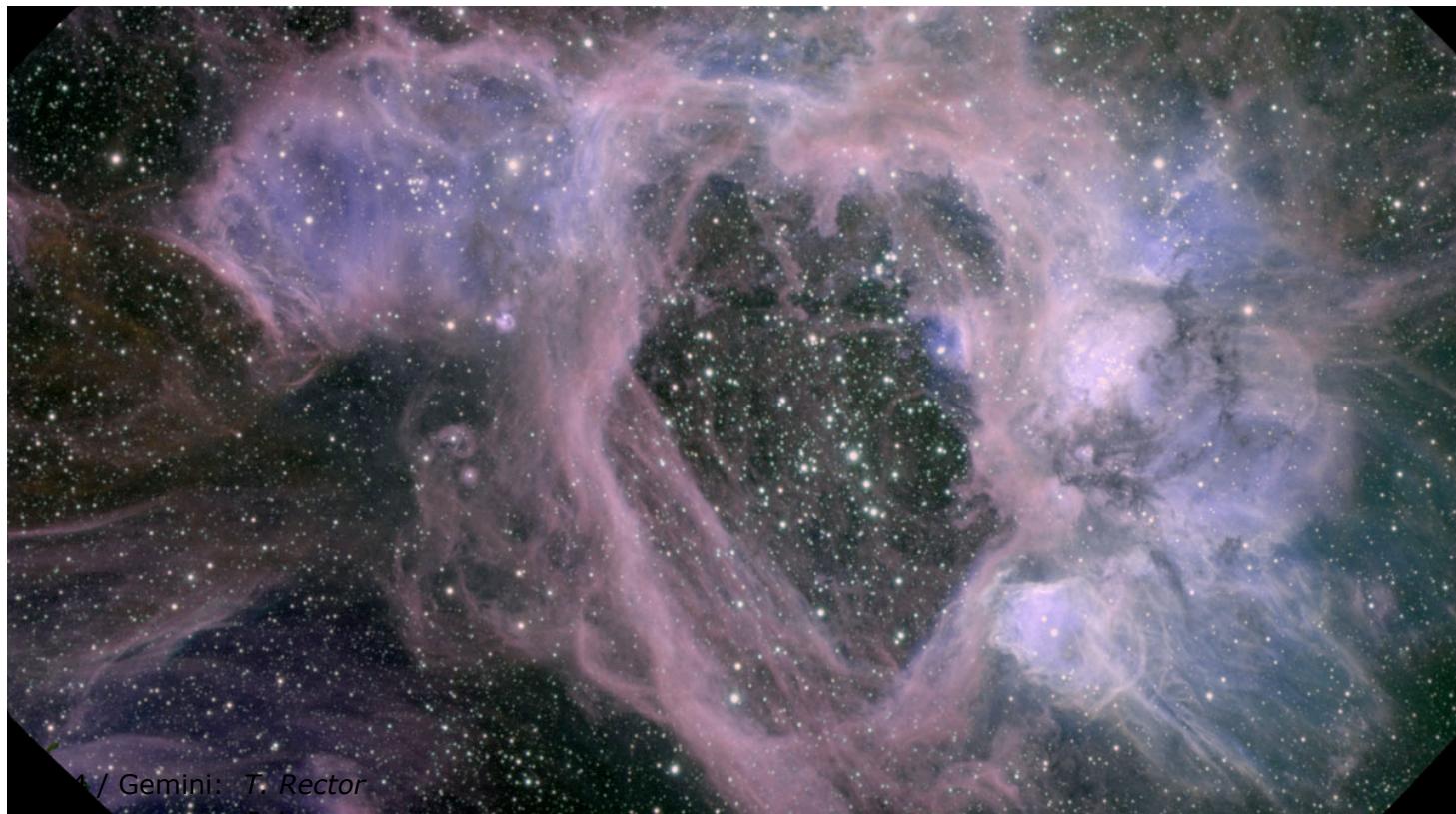
Superbubble origin for CR's $\sim N(E)$, isotope abd's

factor of < 10 ? multi-SN only

Charge exchange? winds too



Is the Problem Real?

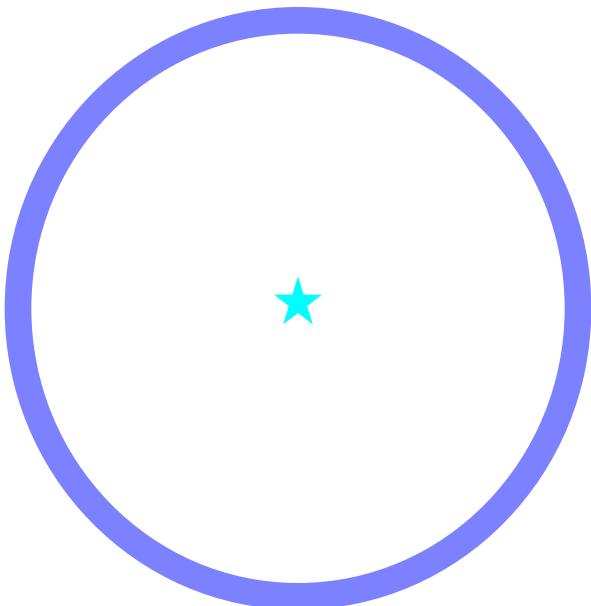


M8 / Gemini: T. Rector



Alternative:

Momentum-conserving evolution

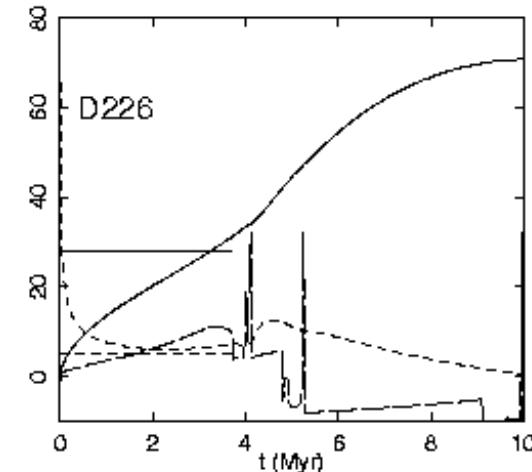
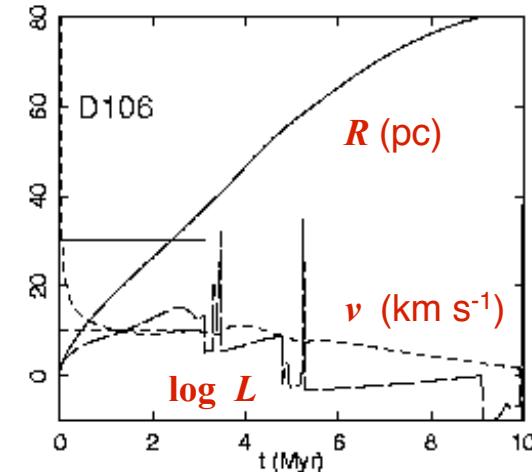


$$R \propto (L / nv_\infty)^{1/4} t^{1/2}$$

Steigman et al. (1975)

$$\text{MC: } \frac{R}{v} \propto t^{1/2}$$

$$\text{AD: } \frac{R}{v} \propto t^{4/5}$$



Oey (1996)



Comparison with data:

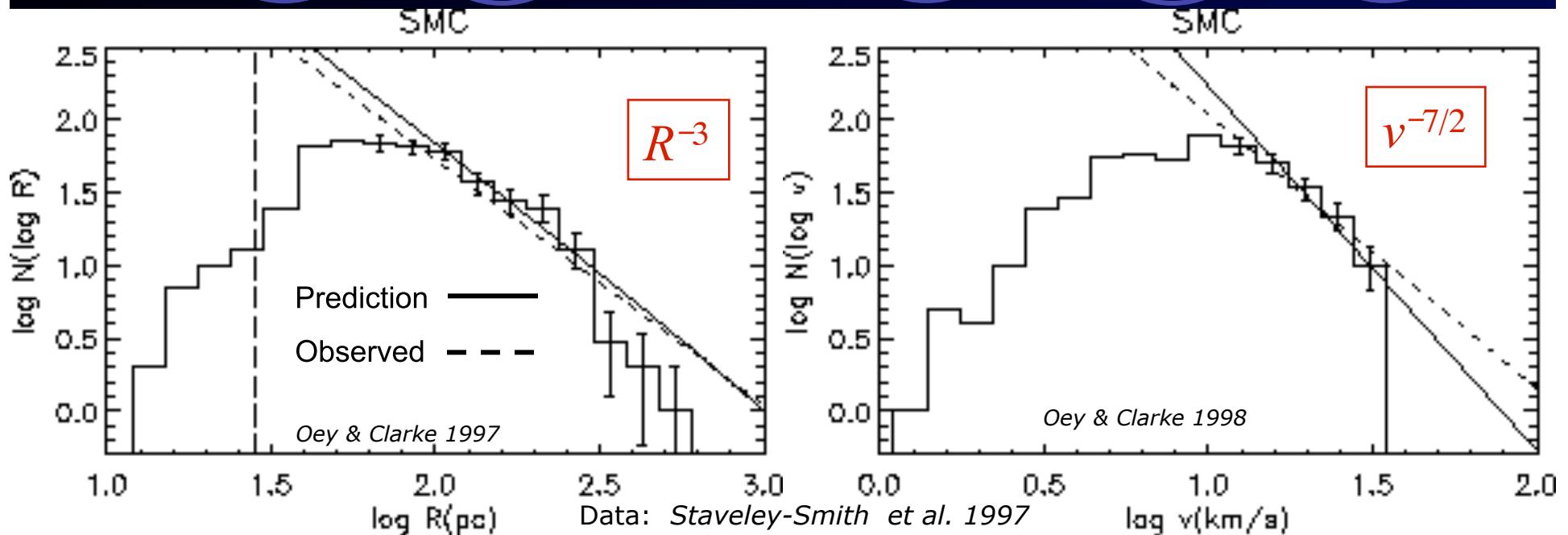
	<u>AD</u>	<u>MC</u>
• Individual dynamics	maybe	maybe not
• Multi-phase ISM	yes	maybe
• R, ν distributions	yes	yes*

*Stall R_f for P -confinement is 1.3x larger than adiabatic

Still $N(R) dR \propto R^{-3} dR$



Statistical properties



Milky Way

Ehlerova (2005)

M31, M33, Ho II

Oey & Clarke (1997)

LMC

Kim et al. (1999)

SMC redux

Hatzidimitriou et al. (2005)

NGC 2403:

Thilker et al. (1998)
Mashchenko et al. (1999)



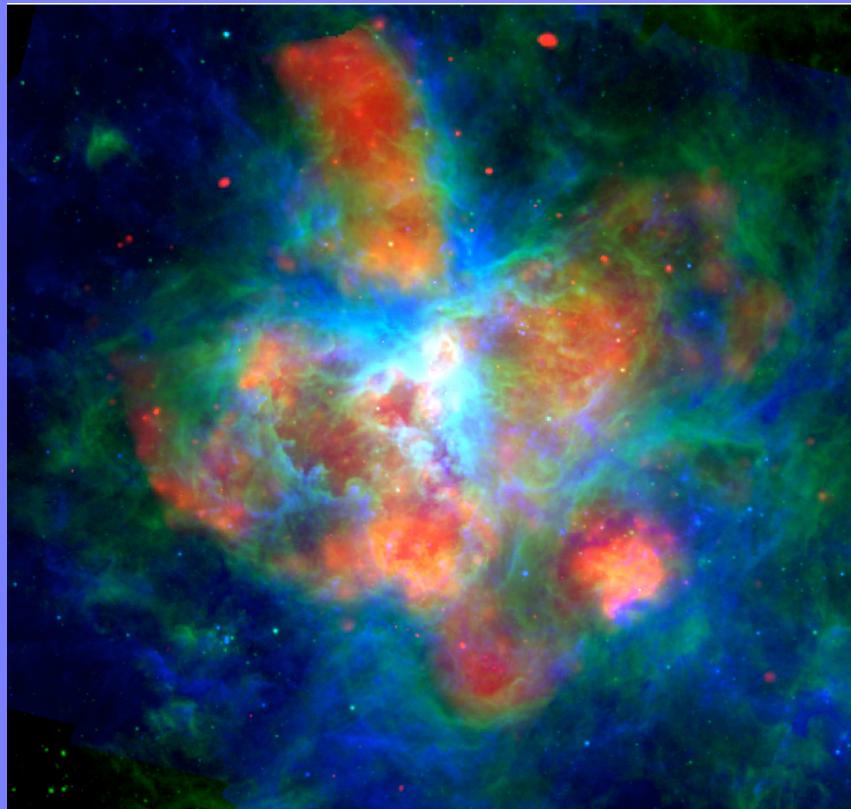
What about SN-dominated bubbles?



L tough!!



Energy Budget: Multiphase ISM



L. Townsley

30 Dor, LMC

- 0.2 – 5 keV
- H α
- 8 μ m

N51 D: *XMM*, Cooper et al. (2004)

N44, DEM L50: *CXO*, Oey et al.



Summary

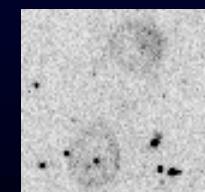
Power Problem for wind-dominated bubbles

Evolution, Environment, Energy budget

- overestimate in \dot{M} ?
- underestimate in n ?
- underestimate in ambient P ?
- cooling by radiation?
- cooling by CR heating?

Future:

- Better multiwavelength data
- More complete modeling
- More objects: *seek trends*



Oey & Massey (1994)

Is Power Problem is real for SN-dominated bubbles?





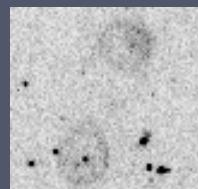
Single Star Bubbles

O Star bubbles

**Consistent with
adiabatic model**

Oey & Massey (1994)
Benaglia & Cappa (1999)
Cappa et al. (2002, 2005)

Small sample



WR bubbles

***Growth rate
discrepancy***

Treffers & Chu (1982)
Garcia-Segura & Mac Low (1995)
Drissen et al. (1995)

Environment

Multiple winds

Instabilities



Single Star Bubbles

M33

$R = 66$ pc

Z362 O9 III

Z364 O9 – B0 I

Size and stellar age consistent
with standard adiabatic model.

Oey & Massey (1994)

H α

(C. Hoopes)

